

Forage Mixture Productivity and Botanical Composition in Pastures Grazed by Dairy Cattle

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ABSTRACT

Some producers believe that planting pastures to several forage species benefits sustainability of grazing systems. We conducted a grazing study to determine if forage species diversity in pastures affects herbage productivity and weed invasion. One-hectare pastures were planted to four mixtures in August 2001 and then grazed with lactating dairy cattle during 2002 and 2003. The mixtures were two species [orchardgrass (*Dactylis glomerata* L.) and white clover (*Trifolium repens* L.)], three species [orchardgrass, white clover, and chicory (*Cichorium intybus* L.)], six species [orchardgrass, tall fescue (*Festuca arundinacea* Schreb.), perennial ryegrass (*Lolium perenne* L.), red clover (*Trifolium pratense* L.), birdsfoot trefoil (*Lotus corniculatus* L.), and chicory], and nine species [the six-species mixture plus white clover, alfalfa (*Medicago sativa* L.), and bluegrass (*Poa pratensis* L.)]. When rainfall was plentiful (2003), there were no differences in herbage yield among the mixtures; all averaged 9800 kg ha⁻¹ dry matter. During 2002, which was dry, the two-species mixture produced less herbage than the other mixtures (4800 vs. 7600 kg ha⁻¹ dry matter). The proportion of nonsown species in the sward was lower for the six- and nine-species mixtures than the two- and three-species mixtures, indicating less weed invasion for these complex mixtures. Red clover and chicory proportions decreased by 80% after 2 yr, and orchardgrass dominated in all pastures by May 2004. We conclude that planting a mixture of grasses, legumes, and chicory will benefit herbage production during dry years and will reduce weed invasion for a few years after planting under management similar to ours. Producers would have to reestablish the chicory and legume components relatively frequently to maintain these benefits.

IN THE NORTHEASTERN USA, grazing land accounts for about 3.5 million ha (USDA-NRCS, 2002) and contributes substantially to the agricultural economy. Forage-livestock operations in this region are shifting from using mainly confinement and stored forages to using intensively managed pastures as the primary forage base (Rotz and Cropper, 1998; Sanderson et al., 2001). Reasons for the change include (i) lower production costs (Ford and Musser, 1998), (ii) improved animal health (Goldberg et al., 1992; Washburn et al., 2002), and (iii) a perceived better quality of life for the farm family (Jackson-Smith et al., 1996).

The role of plant species diversity or forage mixture complexity in pastures has not been well explored (Sanderson et al., 2004). Nonetheless, taking their cue from

the plant diversity of natural grassland communities, some producers in the Northeast often plant complex mixtures of grasses and legumes (Tracy and Sanderson, 2000; Sanderson et al., 2001) because they believe that maintaining a highly diverse botanical composition in pastures benefits persistence, yield stability, and productivity.

Perceived benefits from natural diversity have been linked to increased plant production and greater yield stability in response to disturbance (Minns et al., 2001). The proposed mechanisms behind these responses in natural grasslands include complementarity of resource use, facilitation, or a sampling effect (Sanderson et al., 2004).

Early research on forage mixtures in the USA indicated conflicting results. Clipped plot studies in Connecticut showed that increasing the number of grasses and legumes in a mixture did not benefit herbage yield (Brown and Munsell, 1936). Grazing and clipping studies under irrigation in Utah, however, indicated a positive relationship between herbage yield and the number of grasses and legumes in mixtures (Bateman and Keller, 1956). Recent work with forage mixtures in small plots demonstrated small responses in herbage yield from complex (9 to 15 species of grasses, legumes, and forbs) versus simple (one grass and one legume) mixtures of forages (Tracy and Sanderson, 2004a; Deak et al., 2004).

Research in Ontario, Canada indicated that pastures planted to a complex mixture of six cool-season grasses and three legumes maintained this complexity and increased in productivity after 3 yr of intensive grazing management (Clark, 2001). In New Zealand, pastures seeded with a mixture of 18 to 26 species of cool-season grasses and pasture herbs [chicory and plantain (*Plantago lanceolata* L.)] yielded more herbage under sheep grazing than did simple perennial ryegrass-white clover mixtures (Ruz-Jerez et al., 1991; Daly et al., 1996). The increased production resulted mainly from chicory growth during the summer.

Highly diverse grassland ecosystems may be more resistant to invasion by weeds and pests because of (i) a highly competitive environment created by a greater use of resources or (ii) the inclusion of a few highly productive species, which dominate and preclude invasion (Kennedy et al., 2002). Smother crops are an agronomic example of the latter mechanism. Limited evidence points to both mechanisms operating in pastures. For example, weed abundance was negatively related to the evenness (i.e., the relative abundance and distribution of species) of forage species in both experimental pasture mixtures and in pasture surveys of plant species diversity on farms (Tracy and Sanderson, 2004a, 2004b). Species composition of forage mixtures also affected weed abundance: mixtures based on tall fescue had fewer weeds in the soil seed bank and aboveground

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Table 1. Species, cultivars, and seeding rates used in the four mixtures compared in a grazing experiment conducted at University Park, PA, during 2001 to 2004.

No. species	'Baridana' orchardgrass	'Will' white clover	'Puna' chicory	'Barolex' tall fescue	'Sidekick' Kentucky bluegrass	'Start' red clover	'Norcen' birdsfoot trefoil	'Amerigraze' alfalfa	'BG-34' perennial ryegrass	Total
kg seed ha⁻¹										
2	17	8								25
3	11	6	6							23
6	9		6	14	11	6	6			52
9	6	6	6	6	6	6	6	6	6	54
no. live seeds† m⁻²										
2	1000	600								1600
3	650	460	260							1370
6	530		260	490	1160	200	380			3020
9	350	460	260	210	630	200	380	250	140	2880

† Calculated from laboratory measurements of seed mass and germination.

vegetation than did mixtures based on smooth brome-grass (*Bromus inermis* Leyss.) (Tracy et al., 2004).

Results from ecological studies linking plant species diversity to ecosystem functioning (e.g., primary productivity, resistance to invasion) suggest that managing complex mixtures of plants may be one ecological approach to increase productivity of grazing lands (Tilman et al., 1999; Minns et al., 2001; Sanderson et al., 2004). Our previous research on forage species diversity was done in small plots under clipping or grazing (Tracy and Sanderson, 2004a, 2004b; Deak et al., 2004). Results from clipped-plot studies, where defoliation is uniformly applied and spatial variation is low, may not accurately reflect results from pastures where grazing animals tread on plants, unevenly distribute nutrients in dung and urine, and graze selectively causing patchy defoliation. In this grazing experiment at a large scale, we tested the hypothesis that pastures planted to complex mixtures of forage species would yield more herbage and reduce weed invasion compared with a simple grass-legume mixture.

MATERIALS AND METHODS

We conducted the research at the Dairy Cattle Research and Education Center of the Pennsylvania State University in University Park. In July 2001, existing vegetation at the site was killed with glyphosate [*N*-(phosphonomethyl)glycine] and dicamba (3,6-dichloro-2-methoxybenzoic acid) herbicides, both of which were applied at 1 kg a.i. ha⁻¹. On 29 Aug. 2001, four mixtures of forage species (Table 1) were no-till planted in replicated 1-ha pastures. The mixtures were (1) orchardgrass-white clover; (2) orchardgrass, white clover, and chicory; (3) orchardgrass, tall fescue, perennial ryegrass, red clover, birdsfoot trefoil, and chicory; and (4) Mixture 3 plus white

clover, alfalfa, and Kentucky bluegrass. Mixture 1 is commonly used in the Northeast. We formulated Mixture 2 to include three functional groups (grass, legume, and forb). Mixtures 3 and 4 were formulated to have increasing redundancy in the grass and legume functional groups. Chicory was the only commercially available forb; thus, we were unable to use multiple forb species. We determined the 100-seed mass of each species and used this number in combination with the germination percentage reported by the seed supplier to estimate the number of live seeds planted per square meter (Table 1). The experimental design was a randomized complete block with two replicates (pastures) of each mixture.

Soil at the site is a Hagerstown silt loam (fine, mixed, semi-active, mesic, Typic Hapludalfs). Soil tests (to a 15-cm depth) in 2001 indicated a pH of 6.5, 220 kg ha⁻¹ available P, and 210 kg ha⁻¹ of available K; thus, no fertilizer was required. A portable meteorological station at the site monitored solar radiation, air temperature, rainfall, and soil moisture (at 13- and 61-cm depths) from April 2002 to October 2003 (Table 2).

The pastures were subdivided into smaller paddocks and stocked rotationally with lactating Holstein cows from April through August in 2002 and 2003. Five cows grazed each treatment. The cows were of similar body weight (648 kg), milk yield (47 kg d⁻¹), lactation (3), and days in milk (109). Herbage allowance was 25 kg dry matter cow⁻¹ d⁻¹. Cows were confined to a fresh area of pasture after each milking, which took place each morning at 0500 h and afternoon at 1800 h. Herbage allowance was equalized among treatments twice weekly by using temporary electric fencing to adjust the area allotted for grazing. Cows were fed a maize (*Zea mays* L.)-based supplement (1 kg per 4 kg of milk, 9 kg d⁻¹ maximum) in two equal feedings after milking. Lactating cows were not available after 1 August of each year; therefore, pastures were mob-grazed with 21 dry cows for 2 d in mid-August (2003) and early September (2002 and 2003) to complete the grazing season. Animal performance was not measured on the dry

Table 2. Air temperature, rainfall, and soil moisture at the experiment site in University Park, PA, during the grazing seasons of 2002 and 2003.

Month	Average monthly air temperature			Rainfall			Average monthly soil moisture			
	2002	2003	30-yr mean	2002	2003	30-yr mean	0–13 cm		0–61 cm	
	°C			mm			2002	2003	2002	2003
	°C			mm			m ³ m ⁻³			
April	10.6	9.5	8.7	71	64	74	0.317	0.294	0.329	0.321
May	13.9	13.4	14.8	143	107	92	0.329	0.273	0.333	0.301
June	20.4	18.4	19.5	142	113	102	0.300	0.307	0.322	0.329
July	22.7	21.1	21.8	33	106	92	0.160	0.235	0.293	0.300
August	22.4	21.6	20.9	46	200	81	0.113	0.309	0.268	0.322
September	18.5	16.5	16.8	39	148	82	0.115	0.333	0.247	0.331
October	9.6		10.6	150		72	0.275		0.289	

Table 3. Grazing dates for pastures of the four mixtures compared in an experiment at University Park, PA, during 2002 and 2003.

2002	2003
12 April–3 May	14 April–1 May
4 May–28 May	2 May–23 May
29 May–2 July	24 May–13 June
3 July–26 July	14 June–11 July
27 July–6 September	12 July–11 August
7 September–11 October†	12 August–3 September
	4 September–7 October†

† The amount of regrowth was measured for this period, but the herbage was not grazed.

cows. The experiment was conducted under the approval of the Penn State Animal Care and Use committee.

There were five grazing cycles in 2002 and six in 2003 (Table 3). These were followed each year with a cycle in which regrowth was measured but not grazed. Because of the relatively high herbage allowance necessary for the lactating dairy cows, a large amount of herbage remained after grazing in some cycles. Biosecurity rules at the Pennsylvania State University precluded the use of additional dry cows or heifers in rotation with the lactating cows to clean up residual forage. Therefore, if necessary, pastures were clipped to a 10-cm stubble height after grazing.

Pregrazing herbage mass was measured twice each week during the grazing season with a calibrated rising plate meter (Jenn Quip model, Feilding, New Zealand). Thirty plate readings were taken in each pasture on each measurement date. The plate meter was calibrated by clipping herbage in twenty-four to thirty 0.1-m² quadrats to a 1-cm stubble height on three transects of 8 to 10 quadrats each. Twenty rising plate meter readings were taken on the same transects. Transect means of clipped herbage mass were regressed on transect means of plate meter readings for calibration. A single calibration proved adequate for all pasture mixture treatments within each year. The calibration equation for 2002 was $Y = 353 + 84.5 \times (\text{rising plate reading})$, $r^2 = 0.82$, root error mean square = 318 kg ha⁻¹, $n = 78$. The equation for 2003 was $Y = -30 + 90.6 \times (\text{rising plate reading})$, $r^2 = 0.85$, root error mean square = 295 kg ha⁻¹, $n = 80$.

Postgrazing herbage mass was measured twice weekly during the grazing season by clipping twelve to twenty 0.1-m² quadrats to a 1-cm stubble height on two transects of 8 to 10 quadrats each. Postgrazing samples were taken within 18 h after grazing. We did not use the rising plate meter for postgrazing measurements because we could not obtain reliable calibrations. The pastures and cows were not available for research after May 2004. Therefore, we took a final herbage yield measurement on 14 May 2004 by clipping herbage in thirty 0.1-m² quadrats to a 1-cm stubble height on three transects of 10 quadrats each. All clipped herbage samples (pre- and postgrazing) were dried at 55°C for 48 h.

The species composition of the newly established swards was assessed on 10 Oct. 2001 by counting the individuals and identifying species with a line intercept technique. Three 20-m transects were placed randomly in each pasture and at every 5 m, all species present within a 10-cm distance perpendicular to either side of the line were identified. During 2002 and 2003, botanical composition was measured by clipping and hand-sorting herbage during two consecutive weeks in each of the grazing cycles. A final botanical composition measure was taken on 14 May 2004. At each sampling, herbage in ten 0.03-m² quadrats was clipped to a 1-cm stubble height in each pasture and bulked. The bulked herbage was hand-separated into the sown forage species, unsown forbs and grasses, and dead material. We did not sort to the species level for the

unsown component. All herbage samples were dried at 55°C for 48 h and weighed, and the proportion of each species or component was determined.

Herbage yield data (totals of net herbage accumulation in each grazing period for each grazing season) were analyzed as a randomized complete block design with the mixed models procedure in SAS (Littel et al., 1996). Treatments were considered fixed effects and blocks were random. Years were analyzed separately. Botanical composition data for each period across years were analyzed as repeated measures in a randomized complete block design. Periods were considered fixed and blocks random. In both analyses, a compound symmetry covariance structure best fit the data. Denominator degrees of freedom were calculated with the Kenward–Rogers option in SAS.

RESULTS AND DISCUSSION

Herbage Yield

Year and forage mixture treatments interacted; thus we discuss years separately. In 2002, herbage yield was significantly lower on the orchardgrass–white clover mixture compared with the more complex forage mixtures (Fig. 1). In 2003, the mixtures did not differ in herbage yield. In May 2004, herbage yields averaged 3300 kg ha⁻¹ and did not differ among mixtures (data not shown). The three-species mixture (orchardgrass, white clover, and chicory) yielded 54% more herbage than the orchardgrass–white clover mixture in 2002. Herbage yield did not differ among the three-, six-, or nine-species mixtures. This suggested that yield increased with increasing seeded species richness because of adding a highly productive species (chicory). This is an example of the sampling effect mechanism (i.e.,

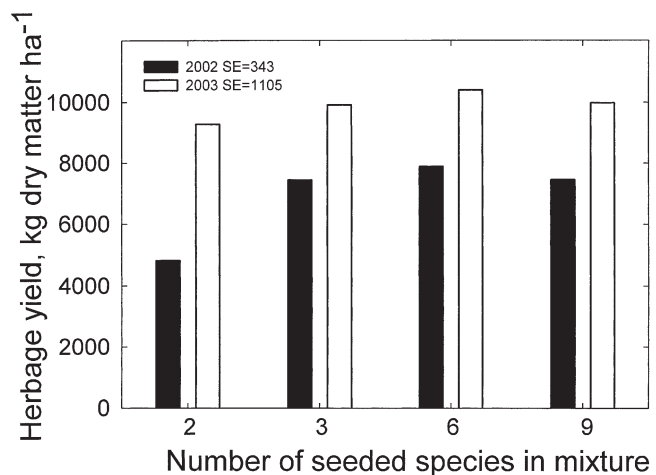


Fig. 1. Herbage yields of pastures planted to four different mixtures of forages and grazed during 2002 and 2003 at University Park, PA. Species sown were two species (orchardgrass–white clover), three species (orchardgrass, white clover, and chicory), six species (orchardgrass, tall fescue, perennial ryegrass, red clover, birdsfoot trefoil, and chicory), and nine species (the six-species mixture plus white clover, alfalfa, and Kentucky bluegrass). Data are totals for the grazing seasons averaged for two replicate pastures. In 2002, herbage yield was lower ($P < 0.05$) on the two-species mixture compared with the three-, six-, and nine-species mixtures. Herbage yield did not differ ($P > 0.05$) among the three-, six-, or nine-species mixtures. In 2003, the mixtures did not differ ($P > 0.05$) in herbage yield.

Table 4. Species presence in pastures of the four experimental mixtures on 10 October 2001 at University Park, PA. Data are averages of four samples on each of three 20-m transects in two replicate pastures.

No. species	Orchardgrass	White clover	Chicory	Tall fescue	Kentucky bluegrass	Red clover	Birdsfoot trefoil	Alfalfa	Perennial ryegrass	Nonsown species†
	percentage of total intercepts									
2	26	28								46
3	8	27	25							40
6	4		20	2	13	14	12			35
9	9	8	22	8	1	12	18	5	9	8

† Predominant nonsown species identified in transect intercepts were quackgrass, bull thistle [*Cirsium vulgare* (Savi) Tenore], dandelion, bedstraw (*Gallium aparine* L.), chickweed [*Stellaria media* (L.) Vill.], shepherd's purse [*Capsella bursa-pastoris* (L.) Medicus], and smooth brome grass.

increasing species richness increases the chance of including productive species) for explaining plant species diversity effects (Minns et al., 2001).

Thus, it appears that complex forage mixtures may have more stable herbage yield during times of stress or disturbance (e.g., soil moisture deficits) as suggested by others (Tilman and Downing, 1994). The hot and dry weather during the summer of 2002 limited herbage growth on the pastures. Monthly average air temperature during the summer of 2002 was 0.5 to 1°C higher than the long-term average, and rainfall in July, August, and September was only 46% of the long-term average (Table 2). Monthly average air temperature during the summer of 2003 was 2.5°C lower than in 2002, and rainfall was well above the long-term average for nearly all of the grazing season. In 2003, the orchardgrass–white clover mixture yielded 92% more forage than in 2002, whereas the yield increases for the other mixtures averaged 33% (Fig. 1).

The number of live seeds planted per square meter for the six- and nine-species mixtures was twice that for the two- and three-species mixtures (Table 1). Because some species in the six- and nine-species mixtures had low establishment success (Table 4), the resulting stands may have been about equal among all mixtures; however, we did not determine seedling or plant densities. The three-species mixture yielded as much herbage as the six- and nine-species mixtures in both years, indicating that the greater seeding rates may not have benefited these mixtures.

Skinner et al. (2004) reported that a complex mixture of forages (chicory, orchardgrass, bluegrass, perennial ryegrass, and white clover) yielded more herbage than a simple (bluegrass and white clover) mixture under both dry and normal soil moisture conditions. The vigorous growth of chicory in the complex mixture accounted for most of the yield increase. In that experiment, they noted that white clover growing in the complex mixture had improved leaf water relations and greater relative growth rate than white clover growing in the simple mixture. They speculated that increased soil moisture in the shallow soil layer resulted from either hydraulic lift of water from deeper in the soil by the chicory taproot or because more water was extracted by chicory from deeper in the soil, leaving more water near the soil surface for shallow-rooted species such as white clover.

In an earlier clipped small-plot experiment, mixtures with three or more species yielded more herbage than two-species mixtures because of the addition of a legume (Tracy and Sanderson, 2004a). Increasing from 3 to 15 species (including perennial grasses and legumes and

perennial and annual forbs) did not benefit herbage production. In another small-plot experiment, we compared mixtures of two, three, six, or nine species of grasses, legumes, and a forb under frequent grazing by beef cattle. The six- and nine-species mixtures yielded more herbage than the two- and three-species mixtures; however, the increased yield resulted mainly from the inclusion of red clover, a highly productive legume (Deak et al., 2004).

Productivity of New Zealand hill pastures, determined in small plots grazed by sheep, was affected more by soil fertility, slope, and location than by plant functional group diversity (Dodd et al., 2004). In that study, identity of the functional group was more important than the number of functional groups in the sward in affecting sward productivity.

Another tenet of plant biodiversity theory is that increased diversity contributes to the stability of grassland ecosystems. In our study, herbage yield increased only 33% in the six- and nine-species mixtures between dry and wet years compared with 92% in the two-species mixture, which indicates greater yield stability for the complex mixtures. In a small-plot study with mixtures of up to 15 species of legumes, forbs, and grasses, Tracy and Sanderson (2004b) found that complex forage mixtures did not improve forage yield or yield stability. Research on New Zealand high-country grazing lands showed that species richness and evenness (an estimate of species distribution in a plant community) were weakly associated with the stability of sheep production (Scott, 2001). Stability of herbage production on temperate grazing lands in southern Australia was not related to species richness (Kemp et al., 2003). Nicholas et al. (1997) reported a high coefficient of variation for low numbers of species and a decreasing coefficient of variation as species number increased, evidence of reduced risk from species-rich grasslands.

Animal performance data are reported separately (Soder et al., 2004). Milk production averaged 35.6 kg cow⁻¹ d⁻¹ in both years with no differences among treatments. Grazed herbage intake averaged 13.7 kg dry matter cow⁻¹ d⁻¹ and did not differ among treatments.

Botanical Composition

Nonsown Species

In 2002, the six- and nine-species mixtures had a lower grazing season average proportion of nonsown species than the two- or three-species treatment (Fig. 2). The nonsown proportion in 2003 was similar in all but the nine-species treatment, which had the least. The non-

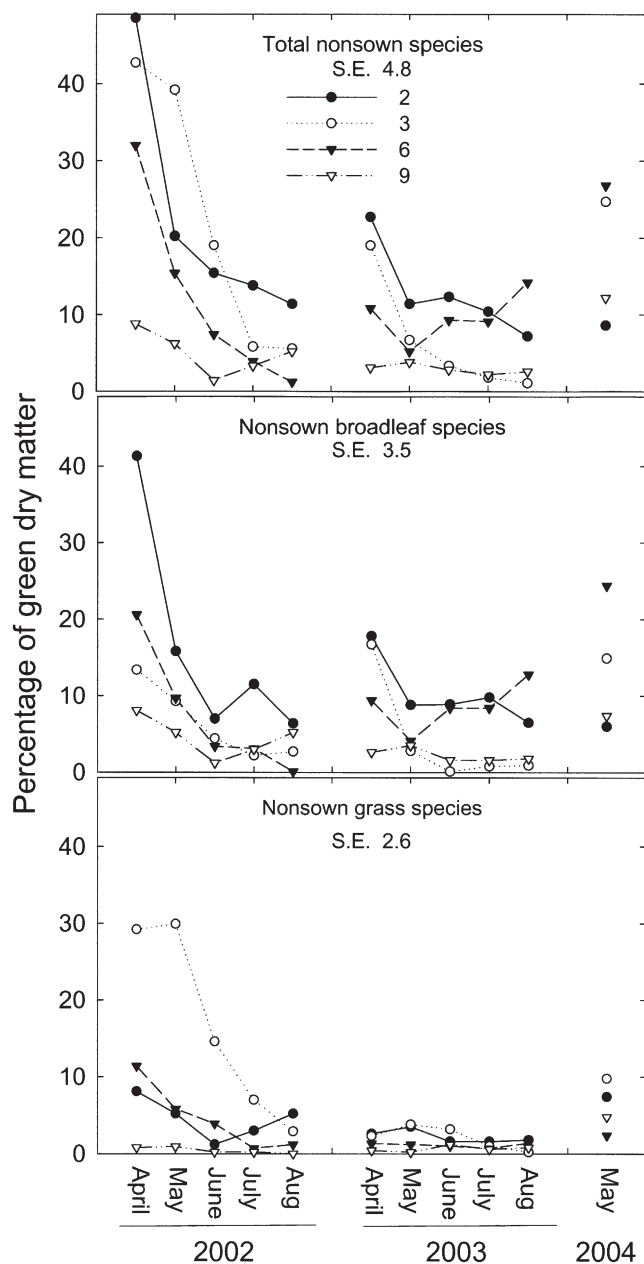


Fig. 2. Proportion of nonsown grass and broadleaf species during 2002 to 2004 of pastures planted to four different mixtures of forages at University Park, PA. Species sown were two species (orchardgrass-white clover), three species (orchardgrass, white clover, and chicory), six species (orchardgrass, tall fescue, perennial ryegrass, red clover, birdsfoot trefoil, and chicory), and nine species (the six-species mixture plus white clover, alfalfa, and Kentucky bluegrass).

sown component was greatest in the spring sampling each year. At the final sampling in 2004, the nonsown proportions were least in the two- and nine-species mixtures.

Most of the nonsown species were broadleaf plants (Fig. 2). Shepherd's purse (*Capsella bursa-pastoris* L.) and pepperweed (*Lepidium* spp.), both winter annuals, were abundant in the spring of 2002, and dandelion (*Taraxacum officinale* Weber in Wiggers) was common during both years. The large decline in the proportion of nonsown broadleaf species during April to June in 2002 probably was due to the disappearance of the win-

ter annual weeds. Quackgrass (*Elytrigia repens* Nevski.) was the most abundant nonsown grass species and accounted for most of the nonsown component in the three-species mixture.

The reduced abundance of nonsown species in the six- and nine-species mixtures suggests that mixture complexity reduced weed invasion. The reduced weed invasion could have resulted simply because the greater herbage mass precluded invasion. If so, we would expect a negative correlation between the abundance of nonsown species and herbage mass. In 2002, however, herbage mass and the proportion of nonsown species were positively correlated ($r = 0.61$, $P = 0.004$) because of high herbage mass and nonsown species in the spring. Herbage mass and the proportion of nonsown species were not correlated in 2003 ($r = 0.08$, $P = 0.72$) or spring of 2004 ($r = 0.38$, $P = 0.66$). Thus, another mechanism must have accounted for the reduced proportion of nonsown species in the pastures planted to a complex mixture of forages.

Weed abundance was negatively related to species evenness in pastures and grazed plots and negatively related to aboveground biomass in other greenhouse and field plot studies (Tracy and Sanderson, 2004b; Tracy et al., 2004). In those studies, species composition seemed to contribute to weed suppression; there were fewer weed seeds in the soil and less weed biomass above ground in mixtures with tall fescue than in mixtures with smooth brome grass (Tracy et al., 2004). In New Zealand hill pastures, the proportion of nonsown species in sward mixtures of several different forage plant functional groups decreased as the diversity of each group increased (Dodd et al., 2004).

Seeded Forage Species

Shortly after planting the experiment, all of the sown species were present in the respective pastures (Table 4). Chicory was relatively abundant, accounting for 20 to 25% of species presence in the three-, six-, and nine-species mixtures. Kentucky bluegrass, alfalfa, and perennial ryegrass had a low presence after establishment and remained less abundant into 2002 and 2003. On the other hand, birdsfoot trefoil was much more abundant after establishment than later in the experiment. Dry soil conditions in late summer and fall of 2001 may have affected germination and establishment of bluegrass, alfalfa, ryegrass, and trefoil. These species are not discussed because they were present at very low levels during the grazing seasons.

In the two-species mixture, white clover increased in 2002, remained steady at about 40% of the green dry matter in 2003, then decreased significantly in spring of 2004 (Fig. 3). In the three- and nine-species mixtures, white clover fluctuated in 2002 but increased greatly in both mixtures in 2003, followed by a substantial decrease in spring of 2004.

Orchardgrass accounted for more than 40% of the two-species mixture in 2002 and 2003, and then in spring 2004, it completely dominated the sward (Fig. 2). Orchardgrass was less abundant in the three- and nine-species mixtures in 2002 and 2003 but became the dominant component in spring of 2004. Orchardgrass dominated in the six-species mixture in 2003 and 2004. Wilson (1969)

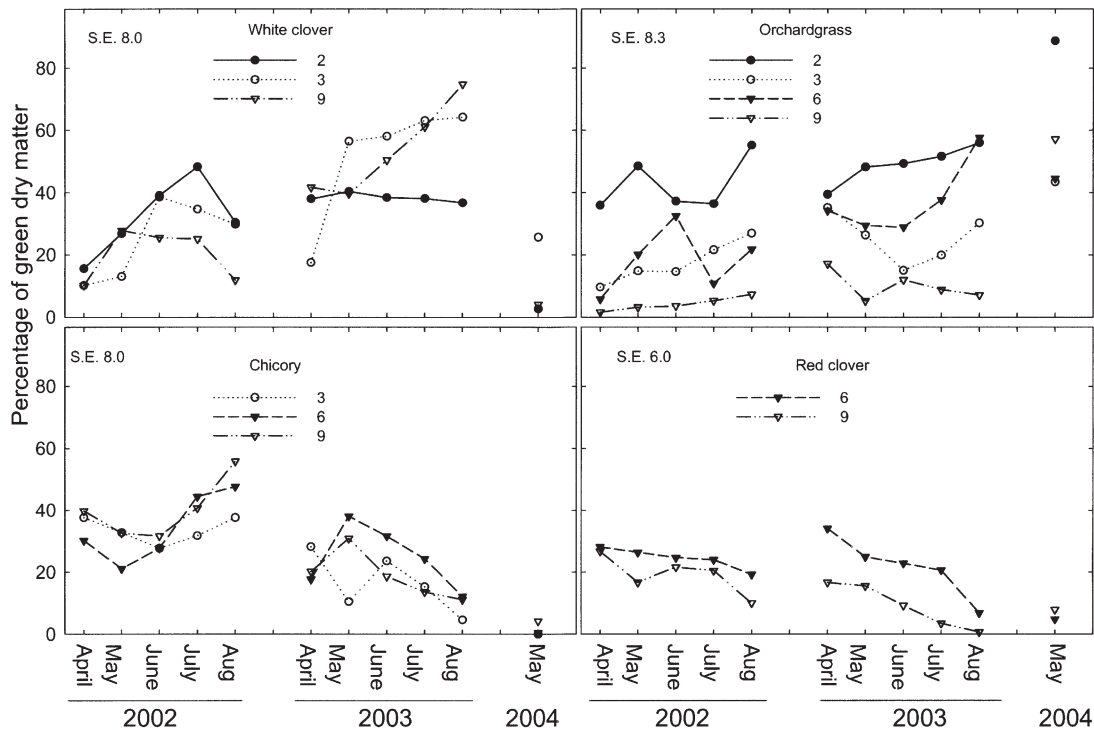


Fig. 3. Forage species composition during 2002 to 2004 of pastures planted to four different mixtures of forages at University Park, PA. Species sown were two species (orchardgrass–white clover), three species (orchardgrass, white clover, and chicory), six species (orchardgrass, tall fescue, perennial ryegrass, red clover, birdsfoot trefoil, and chicory), and nine species (the six-species mixture plus white clover, alfalfa, and Kentucky bluegrass).

reported that orchardgrass dominated in mixtures of smooth bromegrass, white clover, and red fescue (*Festuca rubra* L.) clipped three or four times for hay in Alberta, Canada.

Chicory was a substantial component of the three-, six-, and nine-species mixtures in 2002 but quickly decreased in proportion in 2003 and nearly disappeared from the sward by the spring of 2004 (Fig. 3). Red clover was reasonably abundant in the six- and nine-species mixtures in 2002, but it decreased steadily in both mixtures in 2003 and accounted for less than 10% of the sward green dry matter in spring of 2004. Tall fescue was present in low amounts in 2002 and 2003 but increased to 12 to 13% of the sward in 2004 (data not shown).

The large changes in grass and clover proportions in the swards may have resulted from fluctuations in soil N abundance. Abundant soil N may have become available from the large amount of clover in the swards, which was then exploited by the grass either in fall regrowth of 2003 or in spring growth of 2004. Others have demonstrated an association between soil N cycling and grass–clover relationships in grazed swards (Schwinning and Parsons, 1996; Loiseau et al., 2001).

In the long-term (>100 yr) Park Grass experiment in England, abundant rainfall benefited grasses more than legumes and other species in mixed swards because the erect, taller-growing grasses were better able to compete for light (Silvertown et al., 1994). In our study, both white clover and orchardgrass increased in the sward during the wet summer of 2003, whereas chicory and red clover proportions decreased. Both chicory and red clover are erect, tall-growing species and should have been more competitive for light than white clover. Red

clover is a biennial species, however, and may not persist beyond two or three seasons without reseeding.

Chicory was short-lived in this experiment, as we found previously (Sanderson et al., 2003; Labreuve et al., 2004). The chicory proportion of orchardgrass–chicory–birdsfoot trefoil swards in West Virginia decreased from 80 to 20% under 3 yr of clipping management (Belesky et al., 1999). In our previous studies, we concluded that winterkill caused most of the loss in chicory plants (Sanderson et al., 2003). Skinner and Gustine (2002), however, reported that survival of Puna chicory ranged from 73 to 93% during one winter (2000 to 2001) at State College, PA. In the current grazing study, chicory decreased somewhat from fall 2002 to spring 2003 with the decrease continuing throughout 2003, suggesting that causes other than winterkill may have influenced plant loss. Winter could also have weakened chicory plants, which may have died later in the season.

Thus, despite the relative stability in herbage yield for the complex forage mixtures under our management conditions, individual species abundances in the mixtures were not very stable, and there was a strong pattern of swards simplifying to a few dominant species. Our results agree with others that have shown lower year-to-year variation in plant biomass in plots of greater species richness but no effect of species richness on annual variation in species abundance (Tilman, 1996).

To maintain the legume and chicory components in these forage mixtures, a producer would need to reseed these species and perhaps modify management to favor them. Completely reestablishing pastures every 3 yr by tillage or no-till methods would be expensive. To reduce costs, the clovers could be frost-seeded in late winter.

Research is needed to determine if chicory can be successfully frost-seeded and if that would be economical.

CONCLUSIONS

Complex forage mixtures were more productive than a simple grass-legume mixture during a dry season and also had reduced weed abundance during both wet and dry years. The abundance of individual species, however, fluctuated widely in most mixtures. Legume and chicory proportions decreased greatly after 2 yr, and the swards became dominated by orchardgrass. Our results point to short-term benefits of complex forage mixtures for pastures. Producers would have to reestablish the clovers and chicory relatively frequently to maintain these benefits.

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